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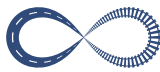
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The importance of ground investigation findings in the design for overhead line electrification foundations

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Abstract

Major part of the investment in UK rail infrastructure has been spent on electrification of the existing network with Overhead Line Electrification (OLE) requiring significant investment to provide the long term benefits. The pressure reduce the cost of electrification works has brought cuts in the ground investigation budgets resulting in a significant drop to one borehole investigation for every 500 m length of rail track and general lack of ground information available for most of the proposed overhead line mast foundations for OLE projects. The current piled foundation design in the UK railway industry is based on experiment and research-developed system (Overhead Line Equipment Master Index - OLEMI), whereby the foundation length is derived for worst-case ground conditions leading to overdesign of foundation size for safety and stability. Ground investigations are only carried out when the ground is very poor or when the foundation designed to the method known as fails. The research method for this paper is based on gathering historical geological data from the British Geological Society, designing pile foundation using conventional design codes and comparing the foundation depth against OLEMI-designed foundations for a case study from the Scottish Central Belt. The results showed that conventional foundation design can provide about 50% savings on overall foundations depth. Detailed analysis showed that some OLEMI-designed foundations did not have enough lateral resistance and anchors had to be added. Moreover, about 99.5% of the OLE foundations were shown to be overdesigned due to the fact that they were installed on firmer soil conditions and shorter foundation would have been sufficient to act against the disturbing acting moment. Therefore, a balanced approach of using geological information from historical sources and allocating additional intrusive and non-intrusive ground investigation was shown to be beneficial for reducing construction costs on overhead line projects.

Keywords: OLEMI, ground investigations, pile foundations, bearing capacity

1 Introduction

This study is based on a case study on piled foundation design for overhead line structures for a major Overhead Line Electrification (OLE) scheme in Scotland. Through analysis of ground investigation results, the aim of this study was to explore conventional civil engineering design process and compare it to standard UK rail foundation design method in order to determine appropriate foundation design solution. One of the objectives of this study was to outline design issues and enhancements that can be made to achieve economical and more environmentally sustainable foundation solutions for the UK rail industry.

Compared to other structural foundations, OLE foundations must satisfy all mechanical, structural, and electrical requirements based on the position of the OLE mast in relation with the track and ground geometry [1]. The designed foundation must be compatible with the existing ground conditions, topography of the site, construction methodology, available site access facilities and be approved Network Rail and satisfy electrical safety standards. The critical factor is the structural loading on the OLE foundation, i.e. the overturning moment at the base of the mast (**Fig 1a**).

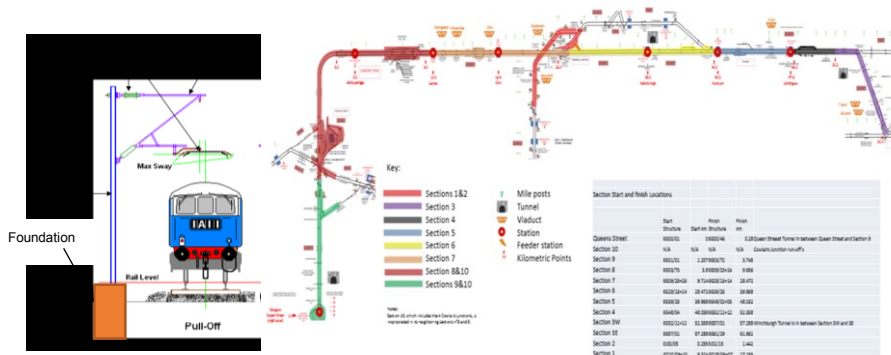


Figure 1. a) OLE components, b) schematic of the case study project extent

The OLEMI method (a.k.a. Basic Design Range (BDR)) is a design manual containing several pre-designed and pre-approved foundations, which can be used at appropriate locations based on ground conditions and the topography of the site [2]. This has been done to meet Network Rail's efficiency commitment in Control Period 5 (CP5) to save design cost and time and requires very little ground investigation works on site. This method, based on the assumption that ground conditions and properties do not significantly affect the moment resistance in most soils, was introduced to suit site construction methods and allows for very little interruption on live rail track [3]. The side bearing capacity (K) and gravitational bearing capacity (P) factors are prescribed for different types of soil and are only applicable to OLE works. For each foundation, the factors are selected based on initial site inspection. Additional ground investigation in term of trial pits or boreholes will only be conducted if there is a doubt on the composition of the ground or if it differs from the soil types prescribed in the manual. The

decision of any additional ground investigation will be made by a Geotechnical or Civil Engineer on site after the initial assessment of ground conditions from window sample holes [4].

The Edinburgh Glasgow Improvement Programme (EGIP; Fig 1b) is a major railway infrastructure improvement project funded by Transport Scotland and delivered by Network Rail. EGIP ground investigation (GI) allocation was 1 exploratory hole at every 500m along the 150km track, aiming at bedrock level confirmation to allow the adoption of OLEMI foundation design. The drift geology comprised mostly glacial till with pockets of alluvial or marine deposits, and very few areas of peat. The bedrock comprised mostly sedimentary rocks.

2 Materials and methods

The research method was based on analysis of the existing ground investigations and re-designing the 1056 steel piles for OLE foundations for the EGIP case study in accordance with Eurocode 7 [5]. 3D ground model (Fig 2a) was produced in Civil3D from existing geological information and GI results (204 boreholes from BSG historical GI). The Eurocode 7 design approach used in this study (Fig 2b) was validated and verified against published results [6]. The re-design focused on short rigid piles in cohesive and granular soils for homogenous ground condition without groundwater affecting the foundation. This was reflecting the OLEMI assumptions where the piles are short rigid and no longer than 5m. The design actions were taken from the project case study structural foundation schedule (SFS) and a calculation showing the maximum lateral pile resistance in different soil types was produced and compared to OLEMI foundation design chart.

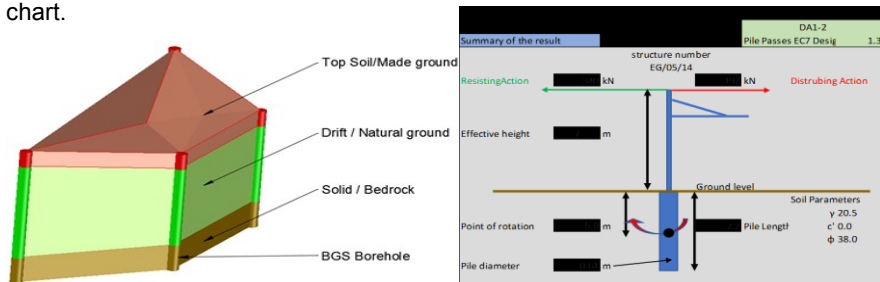


Figure 2. a) An example of the 3D ground model approximation b) stability calculation used in this study.

3 Results

The summary of the number of piles installed in each soil type encountered in the case study project is shown on Figure 3 inset. Generally, most of the piles were built on sandy clays, while the fewest were built in sands. This distribution is representative of the Scottish soils which are generally dominated by sand and clay mixes of glacial origin.

Using the specific ground investigation results for each soil type encountered in the case study, the capacity of a piled OLE foundation was calculated using the method outlined in Eurocode 7. The results of these calculations are shown on Figure 3, where it can be seen that the smallest increase of capacity with pile length can be expected in sand, while the highest increase in capacity with depth can be expected in compacted clayey sand.

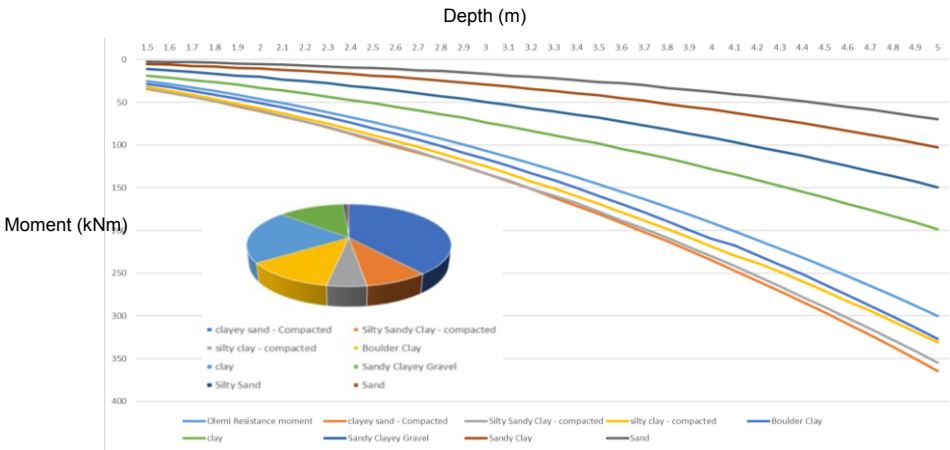


Figure 3. Calculated (EC7) capacity of the pile foundations in different soil types. Inset: Proportion of pile foundations installed in each encountered soil type

When applied to all pile foundations installed in the case study, the comparison between the OLEMI and Eurocode 7 design approach revealed a range of differences. Figure 4 shows these differences detailed for each section of the case study project.

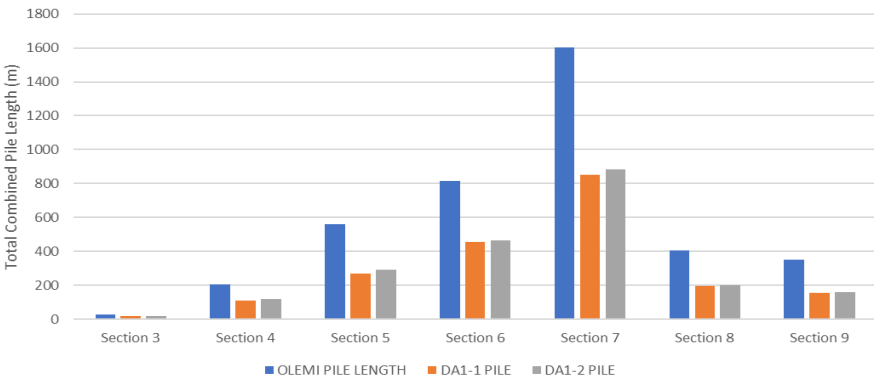


Figure 4. Pile length comparison for different design methods.

The OLEMI design approach appears to overestimate the pile foundation length in each section. As expected, the DA1-2 approach requires increased length of the pile foundation when compared to the DA1-1. The total pile length installed in each section of the case study project was highest in Section 7, where it appears to be almost 50% higher than the total required pile length calculated using the Eurocode 7 approaches (DA1-1 and DA1-2). In this section, the 610 mm diameter steel pile foundations designed using OLEMI principles have a total of 1603.6 m length which compares to DA1-1 pile length with a total of 853 m length (47% less when compared to OLEMI), and DA1-2 pile length of 883 m pile length (45% less compared to OLEMI).

When comparing the relative pile length for each installed pile foundation, it can be seen that 0.5% of the total number of piles in the case study have been efficiently designed i.e. have a design length which differs no more than 10% when OLEMI and Eurocode 7 approaches are compared. The rest of the piles, i.e. 99.5% (or 1051 out of 1056) of the piles, appear to be oversized because they were built on soil material which was stronger and more competent than the one assumed under the OLEMI approach.

4 Conclusion

The results of our calculations indicated that that the OLE pile foundations designed using OLEMI may have lengths approximately 50% higher than the same piles designed in accordance with the Eurocode 7 (DA1-1 and DA1-2). This means it could be more cost effective to design the foundation based on the results of actual, targeted, ground investigations and using using the calculation principles and methods prescribed in the relevant design codes.

The experiences from the case study project shows that only 3 out of 3000 pile foundations designed in accordance with OLEMI actually failed the test loads. This amounts to almost 100% success rate, bearing in mind the potential local variations in ground conditions such as the occurrence of shallow rockhead depth. It should be noted that very few of the foundations on case study project failed to meet the required design length and, hence, failed to resist the test or design loading. Wherever this was the case, and following the test performance, additional anchor foundation was added to the originally designed foundation in order to prop on the piled foundation. In practical terms, it is important to get the pile design just right because overdesigning adds up to the overall project cost [7]. On the other hand, allocating a shorter foundation on OLE which would fail could have significant safety and cost implication as very high voltage power lines are being carried along the tracks to the platforms and station and could cause risk to public safety and reputation.

However, this design approach resulted in approximately 99.5% of the foundations being oversized, which meant 50% more steel was used when compared to a potential Eurocode or BS standard design. Although the OLEMI design covers a multitude of risks and can be considered to err on the side of safety, it is an example of a design system that can be enhanced from a sustainability point of view and in terms of more efficient use of construction

materials. More importantly, there is a need for OLEMI design system to be revisited and to take into account the findings from ground investigation and decrease the overall design costs. This enhancement would include carrying out of targeted and relevant ground investigation to establish the ground conditions at the foundation locations in order to enable the design of most cost effective and technically sound foundations. An argument can then be made, whether it is cost-effective to carry on a relatively large number of ground investigations on site to establish the design ground parameters or to assume the worst case scenario of the ground parameters for design and prescriptively increase the length of the foundations in order to mitigate the risks of failure [8]. In this respect, and based on the opinion of the design engineers involved in the case study presented, it would be beneficial to increase the frequency and relevance of the current level of ground investigations in order to avoid rework due to potential pile failure in unforeseen ground conditions such as a shallow rockhead level. The precision and relevance of such ground investigation could be enhanced with carrying out both non-intrusive (e.g. ground penetrating radar) and intrusive (cone penetration testing) in situ surveys in order to confirm ground parameters and stratification.

References

- [1] International Union of Railways: Calculation of catenary masts and foundations. Utrecht, Netherlands: Office of Research and Experiments. 1957
- [2] Campbell, D.: Series 2 Allocation Design Manual. 6th ed., 2013.
- [3] Clark, P., Wales, R.: Project Advice Note, 3 ed. Network Rail, 2013.
- [4] Shaw, C., Benson, A.: Generic Foundation design for OLE support structures. Network Rail, 2013.
- [5] BS EN 1997-1: Eurocode 7. Geotechnical design: General rules. BSI, London, 2004.
- [6] Tomlinson, M., Woodward, J. and Tomlinson, M.: Pile design and construction practice, 3rd ed, London: Palladian Publication Ltd., 1987.
- [7] Network Rail: Guidance on design of foundation for overhead line structures. (2013). 3rd ed. Network Rail, UK, 2013.
- [8] Mickovski, S.B.: Stabilisation of former trunk road embankment using combined structural and eco-engineering strategies. In: Proc. 3rd Int'l Conf. on road and rail infrastructure CETRA 2014, Split Croatia, 28-30 April 2014, 2014